

one metal. The metal matrix may comprise a single metal, metal alloys and intermetallics. The metal matrix may also have suitable mechanical properties for use in structural applications, such as adequate strength, fracture toughness and fatigue resistance. For example, the metal matrix of the composite material may have a yield strength of at least 10 to 20 MPa, and may have a fracture toughness of at least 5 to 10 MPa \sqrt{m} .

[0020] Some suitable matrix metals include Cu, Al, Fe, Pb, Mg, Ni, Ti, Co, Mo, Ta, Nb, W, Ni, Zn and Sn, and combinations thereof, including commercial alloys within each of these metallic groups. Preferred matrix metals include Cu, Zn, Sn, Ti, Al, Fe, Ni and Co, and combinations thereof.

[0021] In one embodiment, the matrix metal has a relatively low sintering temperature in order to avoid damage to certain types of ferroelastic ceramic particulates. Matrix metal sintering temperatures below about 850° C. may be preferred, e.g., below 800 or 700° C., depending on the type of ferroelastic ceramic dispersed in the metal matrix. The matrix metal may also have a relatively low melting temperature for some applications. For example, melting temperatures below about 1,000° C., e.g., below 900 or 800° C. may be preferred for the matrix metal.

[0022] The matrix metal typically comprises from about 35 to about 95 volume percent of the composite material, for example, from about 50 to about 80 volume percent of the composite material.

[0023] As used herein, the term “ferroelastic ceramic” means a ferroelectric material which undergoes twinning, domain rotation or domain motion of the crystallographic lattice planes when subjected to stress caused by vibrations, acoustical energy, compression, tension, bending, multiaxial loading and the like. The ferroelastic ceramic may comprise any suitable composition which produces the desired vibration damping effect when dispersed in a metal matrix, and which does not react with the matrix metal to an undesirable extent.

[0024] Some suitable ferroelastic ceramics for use in accordance with the present invention include AgNbO₃, AgTaO₃, AlN, BaTiO₃, (Ba,Ca)TiO₃, Ba₄Na₂NbO₃, BaNb₂O₆, (Ba,Pb)TiO₃, (Ba,Sr)Nb₂O₆, (Ba,Sr)TiO₃, Ba(Ti,Zr)O₃, (Ba_{0.777}Ca_{0.133}Pb_{0.090})TiO₃, BeO, Bi₃TiNbO₉, Bi₃TiTaO₉, Bi₄Ti₃O₁₂, Bi₅Ti₃GaO₁₅, Bi₅Ti₃FeO₁₅, Bi₂PbNb₂O₉Bi₂PbTa₂O₉, Bi₃PbTi₂NbO₁₂, Bi₄PbTi₄O₁₅, Bi₄Pb₂Ti₅O₁₈, Bi₂CaNb₂O₉, Bi₂CaTa₂O₉, Bi₄CaTi₄O₁₅, Bi₂SrNb₂O₉, Bi₂SrTa₂O₉, Bi₄SrTi₄O₁₅, Bi₄Sr₂Ti₅O₁₈, Bi₂BaNb₂O₉, Bi₂BaTa₂O₉, Bi₃BaTi₂NbO₁₂, Bi₄BaTi₄O₁₅, Bi₄Ba₂Ti₅O₁₈, Bi_{4.5}Na_{0.5}Ti₄O₁₅, Bi(Na,K)Ti₂O₆, Bi_{4.5}K_{0.5}Ti₄O₁₅, BiFeO₃, Bi₁₂GeO₂₀, CdS, CdSe, CdTe, C₂H₄(NH₃)₂(C₄H₄O₆), (CH₂CF₂)_n, C₆H₁₄N₂O₆, Cd₂Nb₂O₇, CuCl, GaAs, K₂C₄H₄O_{6-0.5}H₂O, KH₂PO₄, (K,Na)NbO₃, KNbO₃, K(Nb,Ta)O₃, LiGaO₂, LiNbO₃, LiTaO₃, LiIO₃, (Na_{0.5}K_{0.5})NbO₃, (hot pressed), (Na,Ca)(Mg,Fe,Al,Li), 3Al₆(BO₃)₃(Si₆O₁₈)(OH,F)₄, (Na,Cd)NbO₃, NaNbO₃, Na(Nb,Ta)O₃, (Na,Pb)NbO₃, Na_{0.5}Bi_{4.5}TiO₁₅, NaKC₄H₄O₆₋₄H₂O, NH₄H₂PO₄, ND₄D₂PO₄, Pb_{0.925}La_{0.05}Zr_{0.56}Ti_{0.44}O₃, (Pb_{0.58}Ba_{0.42})Nb₂O₆, (Pb,Ba)(Ti,Sn)O₃, (Pb,Ba)(Ti,Zr)O₃, (Pb_{0.76}Ca_{0.24})[Co_{1/2}W_{1/2}]_{0.04}Ti_{0.96}O₃+2 mol % MnO, PbHfO_{3+0.65}Pb(Mg_{1/3}Nb_{2/3})O_{3-0.35}PbTiO₃, PbNb₂O₆, Pb(Nb,Ta)₂O₆, PbSnO₃, (Pb,Sr)Nb₂O₆, (Pb,Sr)(Ti,Zr)O₃,

PbTiO₃, PbTiO₃BiFeO₃, PbTiO₃Pb(Fe_{0.5}Nb_{0.5})O₃, PbTiO₃Pb(Mg_{1/3}Nb_{2/3})O₃, PbTiO₃Pb(Zn_{1/3}Nb_{2/3})O₃, Pb(Ti,Sn)O₃, Pb(Ti,Zr)O₃, Pb(Ti,Zr)O₃Pb(Fe_{0.5}Nb_{0.5})O₃, Pb(Ti,Zr)O₃Pb(Mg_{1/3}Nb_{2/3})O₃, Pb(Ti,Zr)O₃Pb(Ni_{1/3}Nb_{2/3})O₃, Pb(Ti,Zr)O₃, Pb(Ti,Zr,Sn)O₃, PbZrO₃, PbZrO₃BaZrO₃, Pb(Zr,Sn,Ti)O₃, g-Se, a-SiO₂, SrBi₄TiO₁₅, Sr₂Ta₂O₇, SrTiO₃, WO₃, ZnO, b-ZnS, ZnSe, ZnTe.

[0025] One group of ferroelastic ceramics suitable for use in accordance with the present invention includes oxides of metals selected from Ba, Sr, Ca, Pb, Ti, Zr, Mg, La and/or Nb. For example, the ferroelastic ceramics may comprise Pb(Mg_{1/3}Nb_{2/3})O₃ (PMN) or metal titanates such as BaTiO₃, PbTiO₃, Pb(Ti,Zr)O₃ (PZT) and/or Pb(La,Ti,Zr)O₃ (PLZT), with BaTiO₃ and PbTiO₃ being particularly suitable ferroelastic ceramics. Metal oxides such as ZnO and SiO₂ may also be suitable.

[0026] The ferroelastic ceramic is provided in the form of particulates which may have any desired shape such as equiaxed, elongated, plate, rod, fiber, and ellipsoidal shapes. FIGS. 2a, 2b and 2c illustrate spherical, spheroidal and disc-shaped particulates, respectively. The particulates are preferably discontinuous and are dispersed in the metal matrix. The particulates may have any desired size, for example, average diameters of from about 0.5 microns to about 2 mm may be suitable, typically from about 0.5 microns to about 100 microns. Disc-shaped reinforcements may provide high levels of twinning. Reinforcement geometries that favor high load transfer from the matrix to the reinforcement (aspect ratios less or greater than one) will lead to higher damping potential as predicted by this model.

[0027] A composite was made by blending Cu, Sn and BaTiO₃, followed by liquid phase sintering at 820° C. for 6 minutes to form a (Cu—Sn)BaTiO₃ composite material. Referring now to FIG. 3, a plot of the damping capacity (tan delta) as a function of temperature for the Cu—Sn matrix with bulk BaTiO₃ particulates. Composites with 30 and 50 percent BaTiO₃ by volume were tested. Tan delta is a loss coefficient representing damping capability. Below the Curie temperature, damping in the composites is due to three mechanisms: ferroelastic-damping from the reinforcement, composite damping due to interfacial relations, and matrix twinning. Above the Curie temperature only the latter two mechanisms contribute to damping in the composites. A distinct decrease in the damping capacity of the BaTiO₃ is observed at the Curie temperature. Thus, the damping properties of the composite are due in part to the ferroelastic character of BaTiO₃ below the Curie temperature. Ferroelastic damping results from the stress-induced twinning of the ferroelastic domains during cyclic loading. Reorientation of the domains occurs by formation of the 90 degree twins.

[0028] The ferroelastic ceramic particulates typically comprise from about 5 to about 65 volume percent of the composite, typically from about 20 to about 50 volume percent. Each ferroelastic ceramic particulate may comprise a single crystal, or may comprise multiple crystals or grains. The ferroelastic particulates can be randomly dispersed and oriented within metal matrix with respect to any reference direction. The present composite materials possess favorable vibration damping, e.g., a vibration damping loss coefficient of greater than 1×10⁻⁴. For example loss coefficients (tanδ) of greater than 0.1 may be achieved, typically greater than 0.001.